MACHINE TOOLS SELECTION IN PROCESS PLANNING USING THE AHP METHOD

Katarina CEROVŠEK[1], Predrag ĆOSIĆ[2]

[1]Croatian Army
Karlovac, Croatia

[2]University of Zagreb, Faculty of Mechanical Engineering and Naval Architecture
Ivana Lucica 5, Zagreb, Croatia

Abstract

The paper elaborates the problem of decision making in the machine tools selection in technological process planning using the Analytic Hierarchy Process (AHP) method, one of the most popular methods of professional scenario analysis and decision-making. The application of the AHP method in solving multiple criteria decision making is illustrated through a practical example using Expert Choice (EC) software, which is based on the AHP method. A real machine tools selection problem set in the EC by entering the real data is presented. The finally obtained results were analyzed.

Keywords: Analytic Hierarchy Process, Decision Support Systems, Machine tools selection, Expert Choice software

1. INTRODUCTION

The globalization of business, global competitive economy and reducing the lifetime of the product are forcing companies to use new production equipment that is being introduced continuously into the market as a result of rapid technological development. Wrong selection of the machine tool can negatively affect productivity, accuracy, flexibility and manufacturing capabilities, and thus the overall company production efficiency. Therefore, decision on the selection of the machine tool is one of the essential parts of the production process for many companies [1]. Choosing a machine tool can be considered a multiple criteria decision problem [2], since it is necessary to choose the best from a number of different alternatives offered, in the presence of many usually conflicting criteria. One of the most popular methods for multiple criteria decision making is the Analytic Hierarchy Process – AHP [3, 4]. It enables decision-making by consistent evaluation of hierarchy consisting of objectives, criteria and alternatives. Also, this method is realized in information technology variant as Expert Choice software, used for analysis, synthesis and strengthening of complex judgments and estimates. Because of the wide range of alternatives available, machine tools selection is a long and time-consuming process that requires extensive knowledge and experience of engineers, managers and manufacturers of machine tools. In real-life situations, one generally relies on intuition and experience when choosing a machine tool and there is no control parameter for this decision, which is not the case with the AHP. In this way the AHP provides a faster and better solution to the problem as well as better utilization of production capacity.

2. IMPORTANCE OF MACHINE TOOLS SELECTION IN PROCESS PLANNING

There are two cases of machine tools selection: machine tools selection as part of investment, and machine tools selection in defining the technological process planning [1]. This paper deals with machine tools selection as one of the important steps in defining the technological process planning. In this case a machine tool is being selected from the existing range of machines in the company production plant. The main difference compared to the case of the machine tools selection in investments [5] is setting the criteria for the selection of the machine.

There are a number of factors that influence the choice of a machine tool during the technological process planning and which can be considered as criteria for the selection of the machine tool. The decision maker needs to define the most important criteria. This also requires the existence of the input data for these criteria from a database of available machines in the company production plant. Below are listed some of the most commonly used criteria when choosing a machine tool.

1. **Production quantity** – It significantly affects the machine tools selection in the sense of economic parameters such as price of the machine, the cost of materials and price of the tools used. It also affects the delivery time and batch size of workpieces. For example, for a smaller quantity of workpieces and satisfactory machine availability, delivery time is shorter.
2. **Machining type** (milling, turning, drilling…)
3. **Geometrical features of the machine** - The selection of the machine tool according to this criterion depends on the shape and dimensions of preparation.
4. **Machine availability** - influential criterion since it should meet the requirement of the desired delivery time of the product. Thus, the machine with the smallest occupying time or sufficient availability for the manufacturing of products in a given period should be chosen.
5. **Complexity of the workpiece** - This criterion is related to the criteria of productivity and automation. However, according to the authors of this work it is important because it includes important subcriteria that are related to the product such as number of required machining axes, number of required production operations, number of required tightening, production time for one piece.
6. **Productivity** - The most important criterion viewed from an economic standpoint. Production costs should be as low as possible so that the company could make a profit on a given product, which depends on the optimal operating conditions, the price of working hours and the shortest possible production time for one part.
7. **The automation level** - Closely linked to the criterion of productivity. The productivity grows with the increase of the level of automation and the number of workpieces in the series. Also, depending on the complexity of the workpiece, higher or lower level of automation is required.
8. **Accuracy** - This criterion implies the positioning accuracy of the workpiece which depends on the tightening of the workpiece and describes the deviation of the value measured of its actual value, and the repeatability read of measurements that refers to the accuracy of the axis.

3. DECISSION SUPPORT

Decision support system (DSS) [2] is defined as an information system designed to support the business and organizational decision-making. DSS gives a decision-maker the ability to select the solution with the aid of an appropriate algorithm or method, based on the information given by the decision maker. The system has the ability to interact with the user, enabling thus the users to explore and analyze the consequences of possible decisions on the business environment.
Such a decision support system is Expert Choice software which is based on the AHP method and uses limited data and parameters provided by decision makers in order to facilitate the decision-maker in analysis of the situation.

3.1 The AHP method as a part of decision support

The AHP method [3] is one of the most popular methods for multi-criteria decision making. This method is based on a hierarchical structure, which means that complex decision problems are decomposed into simpler elements, which are then linked into a model with a multi-level, hierarchical structure. It enables decision-making by consistent evaluation of hierarchy consisting of objectives, criteria and alternatives. This method is popular primarily because it is very similar to the way an individual intuitively solves complex problems by dismantling them into their simpler forms. In this way even the most complex problems can be broken down into a hierarchy in such a way that analysis involves quantitative and qualitative aspects of the problem.
Advantages of the AHP in comparison to other multi-criteria methods are:

- Method flexibility, intuitive closeness to decision-making and the ability to verify inconsistencies,

- Interactive structuring problems by level in hierarchy and evaluating the hierarchy of elements in pairs, which is simple and practical,
- An analysis of the assessment and determination of weights of all the elements in the hierarchy established by strictly mathematical model,
- It helps capturing the subjective and objective measures of assessment reducing bias in decision making,
- Supports collective decision-making by consensus.

Despite the popularity of the AHP method, there are some problems related to its application. Human factor has significant influence on EC. Even when there is detailed and clear information about the future, human judgments about values and choices are still the basis for making good decisions. However, EC is a decision support system and it significantly increases the ability to make high-quality and efficient decisions. Problem solving process by using the AHP method can be explained in four basic steps as shown below.

3.1.1 Structuring the decision making problem and selection of criteria

The first step includes defining the problem and creating a hierarchical model of decision problems. In decision making a problem is decomposed into its constituent parts, simpler components. This structure consists of a goal at the highest level, criteria and subcriteria at lower levels, and alternatives to the bottom of the model. Figure 1 shows a basic AHP model with hierarchical structure.

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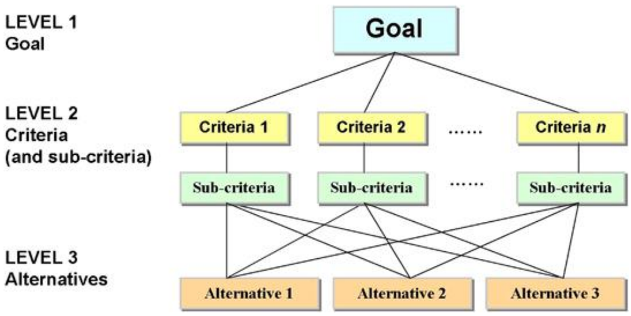


Figure 1 Basic AHP model

3.1.2 Setting criteria priorities by paired comparisons

In this step the decision maker has to determine for each pair of criteria, for example, how much is the criterion *A* more important in relation to the criterion *B*. In each node of the hierarchical structure of the problem elements of this node are being mutually compared by using the Saaty scale which is shown in Table 1.

Table 1 The Saaty scale

The Fundamental Scale for Pairwise Comparisons		
Intensity of Importance	**Definition**	**Explanation**
1	Equal importance	Two elements contribute equally to the objective
3	Moderate importance	Experience and judgment slightly favor one element over another
5	Strong importance	Experience and judgment strongly favor one element over another
7	Very strong importance	One element is favored very strongly over another; its dominance is demonstrated in practice
9	Extreme importance	The evidence favoring one element over another is of the highest possible order of affirmation
Intensities of 2, 4, 6, and 8 can be used to express intermediate values. Intensities 1.1, 1.2, 1.3, etc. can be used for elements that are very close in importance.		

The Saaty scale is a ratio scale that has five degrees of intensity and four intermediate steps, each of which corresponds to a value judgment about how many times one criterion is more important than another. After the criteria comparisons their local weights (priorities) are being calculated.

3.1.3 Pairwise comparison of alternatives under each criterion

Alternatives are being compared with each other in pairs, particularly according to each criterion, and also by the Saaty scale and their local priorities are being calculated. Ultimately, the overall priorities of the alternatives are being calculated.

3.1.4 Sensitivity Analysis

Sensitivity analysis is being conducted in order to see how changes in the input data reflect the overall priorities of the alternatives.

3.2 Consistency

Ranking the alternatives based on the pairwise comparisons can be a problem if alternative assessments are inconsistent. Inconsistent estimates may occur, for example, due to the subjective assessment of the importance of the criteria, taken by decision makers who do not possess sufficient knowledge of the given decision making subject. The AHP method allows monitoring the consistency of assessment at any time in the process of comparing pairs, and identification and analysis inconsistencies of decision makers in the process of comparing the elements of the hierarchy. Consistency of assessment is measured by the consistency ratio (CR). It is believed that consistency is tolerable within limits if the CR is less than 0.10, in which case the assessment of the relative importance of the criteria (priorities of alternatives) is considered acceptable. If the CR is much higher than 0.10, estimates are unreliable because they are too close to chance and conducted assessment is worthless or has to be repeated.

4. USE OF EXPERT CHOICE SOFTWARE

Expert Choice (EC) [6] is one of today's most popular tools to support business management. It is a collaborative software package for decision support, based on the analytic hierarchy process. The program provides different possibilities of conducting sensitivity analysis, and is especially effective at solving the problem of multi-criteria decision making. EC allows users to create different reports, and is particularly useful for "what-if" scenarios in strategic planning and project budget. Today, Expert Choice is used in the business world in a variety of organizations for different purposes such as: distribution of funds, assessing workers and decisions on salaries, overall quality of investment management, quality function development and value price, formulating marketing strategies, selection of alternatives and prediction of the likely results of the analytical and planning, decision-making group, evaluation of technical plans, production and operations management, etc. Expert Choice is therefore a system of analysis, synthesis and substantiation of complex judgments and estimates, which significantly increases the ability to make high-quality and efficient decisions, despite the complexity. However, it cannot replace human evaluations which are still the basis for good decision making.

5. CASE STUDY- MACHINE TOOLS SELECTION

This section presents a practical application of Expert Choice 11 software (EC 11) in the selection of the machine tool for a specific product (workpiece). The case study uses the real data related to products and machine tools from Metal Product Ltd, an electrical equipment production company, located at Đačka Cesta 70, ODRA, 10020 ZAGREB, CROATIA.
The case study considers a machine tool selection problem for a real product "Body MP1030", Figure 2. The production conditions are the following:

- Business hours of operation are organized in two shifts, lasting eight hours, five days a week, which amounts to eighty working hours per week,
- Production quantity: 50,000 pieces,
- Delivery time: 6 months,
- The facility has three vertical milling machining centres which are appropriate for manufacturing this product,
- The task is to choose the best machine among available machines.

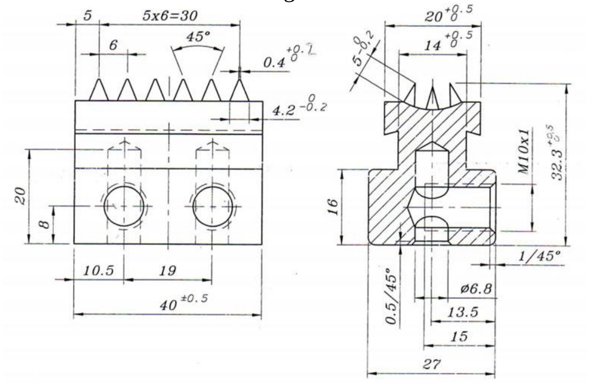


Figure 2 The Body 1030 – Product sketch

Table 2 shows the real data database with the three machines and their characteristics.

Table 2 Database of the milling machines

No	MACHINE TOOLS:		Super VF3	VCE 500	DMC 65V
1	General data	Company	HAAS	MICRON	DECKEL MAHO
		Machine type	Vertical Machining Centre	Vertical Machining Centre	Vertical Machining Centre
		Dimensions of the machine (height x weight x length)	2750x3900x2700	2600x3000x2600	3420x3250x2420
		Axis number	3+1	3	3
2	Main spindle	Maximum power spindles [kW]	22.4	15	25
		Maximum speed [rot/min]	12000	7000	12000
3	Tool head	Number of tools positions	24	20	30
4	Additional functions		A-axis;	-	Changing the palette

			Dividing head; Rinse the spindle; Quick tool change (2.4 s)		(2x) - 5 s; Rinse the spindle
5	Working area	Table length [mm]	1219	600	850
		Table width [mm]	457	450	540
		T-slot [mm]	16 (5x)	16 (5x)	14 (5)
		The maximum permissible table load [kg]	800	600	250
6	Axis travel and feed rates	X axis [mm]	1016	660	850
		Y axis [mm]	508	350	500
		Z axis [mm]	635	520	400
		Working feedrate [mm/min]	21,000	16,000	20,000
		Fast feed rate [m/min]	35	22	30
7	Accuracy	Positional accuracy (X axis; Z axis)[μm]	0.005	0.005	0.005
8	Working hour cost, kn/h		133.50	116.40	99.70

For this case study three scenarios will be worked out. They are shown in Table 3 below. The difference between these scenarios is in different machine availability for each scenario.

Table 3 Three scenarios with different machine availability

Machine tool	**Super VF3**	**VCE 500**	**DMC 65V**
Scenario 1	70 %	80 %	80 %
	In this scenario two alternatives are equal and have the highest priority according to the criterion of availability: DMC65V – the best working hour price and the best manufacturing time. VCE500 – the second-ranked alternative with respect to the working hour price and number of axis machining. This scenario is set up this way to check the sensitivity of the EC program to the defined weights of the criteria. It is expected to select the alternative DMC65V.		
Scenario 2	70 %	80 %	50 %
	In this scenario the percentage of the availability of the alternatives DMC65V, which is assumed to be the best, is reduced on purpose, while the availability of the remaining alternatives remains the same. The aim is to demonstrate the ability of the program EC to select the next following best alternative with a higher percentage of availability, but also the optimum values according to other criteria. It is expected to select the alternative VCE500 with the best availability and good working hour price.		
Scenario 3	80 %	80 %	50 %
	In this scenario the alternatives Super VF3 and VCE500 are equal according to the criterion of availability. The aim is to show how much the criterion of productivity affects the selection of alternatives in relation to the criterion of the automation level. It is expected to select the alternative Super VF3 because of the short manufacturing time, since this criterion is assigned greater importance.		

The problem is set in the EC software. The hierarchy and criteria that are important for solving this problem have been defined, Figure 3.

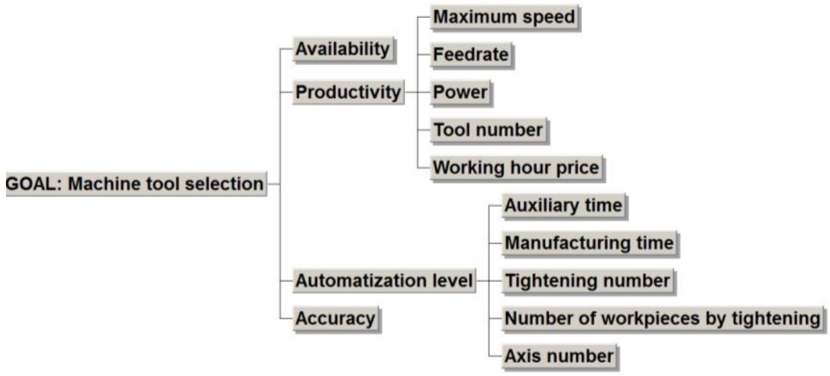


Figure 3 Hierarchical structure– machine tool selection for the product “Body MP1030“

5.1 Assessing alternative priorities

In this step, an assessment of each alternative in relation to each defined criterion will be separately made.

5.1.1 Assessing alternative priorities by the criterion of availability

The alternatives were evaluated using the "Ratings" formula. The intensity estimates are defined as a scale showing the percentage of availability of the machine within the value of 10% to 100%, which is shown on the top of Figure 4. Figure 4 shows the availability of the machines for the three scenarios on the left side and the final result on the right side of the figure.

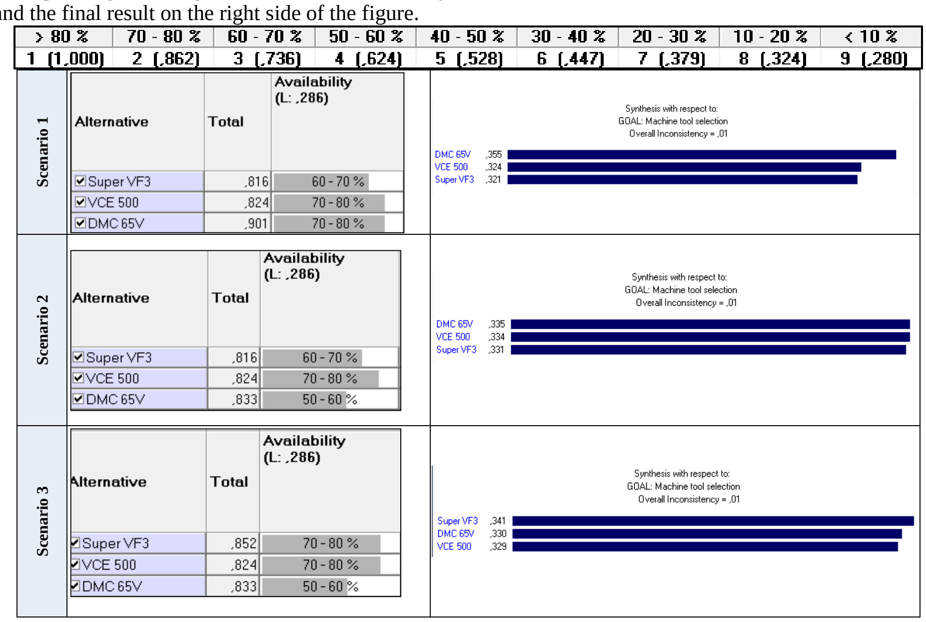
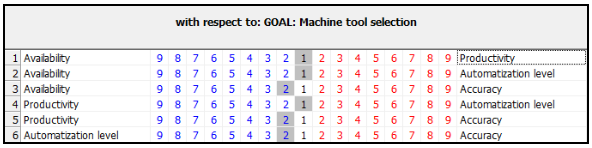


Figure 4 Assessing alternative priorities by the criterion of availability

5.2 Assessing the weights of the criteria

Figure 5 shows pairwise comparisions of the main criteria of the problem from which it is evident that the criteria of productivity and automation have the highest importance.



with respect to: GOAL: Machine tool selection

1	Availability	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Productivity
2	Availability	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Automatization level
3	Availability	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Accuracy
4	Productivity	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Automatization level
5	Productivity	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Accuracy
6	Automatization level	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Accuracy

Figure 5 Assessing the weights of the criteria

5. 3 Results for decision-making problems

The solutions for all the three scenarios are shown in Figure 4 above. Figure 6 shows the Model View window with the solution of decision-making problems under the first scenario. It is evident that the optimal solution is the machine DMC 65 V.

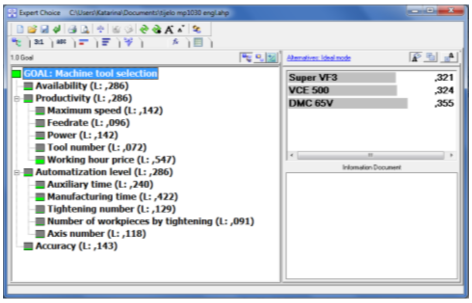


Figure 6 Model View window

5.4 The results sensitivity analysis

Figure 7 shows the results sensitivity analysis in Dynamic Diagrams for each of the three scenarios. It can be seen from the diagram on the left side of the figure that the weights of all the criteria remained unchanged, while on its right side different shares of the availability criterion in each alternative and its impact on the overall ranking of alternatives are shown.

Figure 7 Dynamic Sensitivity Diagram

6. CONCLUSION

After the results synthesis was completed, the solutions to the given problem were analyzed. The conclusions were made concerning the sensitivity of the program Expert Choice to the variation of defined factors, as well as its reliability and capacity to select the optimal alternative. The program demonstrated good sensitivity and the resulting solution to the given problem is in line with expectations.

Based on all the above-mentioned facts it can be concluded that Expert Choice is a very useful tool in solving the problem of tools selection during the design of a technological process and thereby it significantly reduces the time required for making a reliable decision on the selection of the available alternatives, and significantly simplifies the whole process. Future research could continue in the direction of solving the problem of distribution of machine tools (production resources) to more products at the same time.

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